BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: Critique and Extension of Proposed Ionless Mass Spectrometer Experiment Case 710

DATE: November 15, 1968

FROM: R. N. Kostoff

ABSTRACT

This memorandum discusses the ionless mass spectrometer proposed by Dr. Kendall[1] for planetary atmosphere analysis. The first portion examines the fundamental operation of the device, the second section concerns itself with application of the instrument to a Mars mission, while the final paragraphs show what could be obtained if the operation of the spectrometer system were modified. It is concluded that inclusion of the device on a Mars Probe experiment package might in some circumstances be justified.

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MEMORANDUM FOR FILE

Instrument Operation and Error Analysis

Operation of the Kendall mass spectrometer is simple relative to that of a typical mass spectrometer. For inlet pressures up to ∿100 mm Hg., no gas pumping is required, nor at any time is ion production necessary. In its working mode, Kendall's device requires measurement of pressure difference between two similar calibrated hollow chambers vs. time, with each chamber inlet pressure being equal and given the same step changes in time (See Figure 1). For a test gas consisting of a single component, there exists one critical point on the pressure difference vs. time curve. This is the finite time when ΔP, the pressure difference, is equal to zero (t_o, on Figure 1). By adjusting the time when the inlet pressure is pulsed (t_j, on Figure 1), the slope of the ΔP-t curve (at $\Delta P = o$) can be made quite steep, thereby defining t_o more precisely and reducing the error in critical point location. The major uncertainty in molecular weight determination for a single component gas is given by the following expression:

$$\frac{dM}{M} = 2\left\{\frac{dt_j}{t_j} + \frac{\left[\frac{dt_o}{t_o} + \left(1-\frac{t_j}{t_o}\right)\left(\frac{dt_o}{t_o} + \frac{dt_j}{t_j}\frac{t_j}{t_o}\right)\right]}{\ln \frac{t_o}{t_o - t_j}}\right\}$$

where dt_j and dt_o are the uncertainties in measuring t_j and t_o, respectively, and dM is the resulting molecular weight uncertainty. $\frac{dM}{M}$ is equal to no more than a few per cent error when realistic values are inserted for t_o, t_j, dt_o, and dt_j. The factor of 2 exists because $M^{1/2}$, rather than M, is the quantity measured.

For a multi-component gas mixture, determination of composition (partial pressure of each gas component) is subject to much greater uncertainty than is determination of effective mixture molecular weight. The fundamental mixture pressure-time curve is a sum of exponentials, each exponential being representative of a mixture component. Mean molecular weight determination involves approximating the actual pressure-time curve by a single exponential, whereas constituent determination involves decomposing the experimental curve into the separate exponentials which characterize each gas species. Obviously, the former procedure is inherently more accurate than the latter. To quote from Reference 5 of Kendall's paper (a previous study by Kendall), where he discusses the results of an experiment in which air was the test gas:

> "The air curve indicates a predominant constituent at mass 28, but noise, drift and other defects of the capacitance manometer have so far prevented resolution of the two components."

Thus, small experimental errors produce small errors in mean molecular weight determination, but can produce extremely large errors in composition determination. As the molecular weights of the component gases converge, composition resolution becomes increasingly difficult. For example, in the limit of identical molecular weights (CO and N_2, as a typical case), there exists no way of distinguishing between component abundance. If air, whose major components have a ratio of square root of molecular weight of approximately 1.07, could not be resolved into its components, then it does not appear realistic that a probable Martian atmosphere (CO_2 and N_2), whose major components would have a ratio of square root of molecular weight of approximately 1.25, could be resolved into components with any reasonable degree of accuracy. Thus, the Kendall mass spectrometer appears to be quite useful for determining the effective molecular weight of a gas mixture, but much less useful for obtaining mixture composition.

Application to Entry Mission

If major importance were attached to accurate resolution of atmosphere components, then a typical mass spectrometer with pump would be more desirable to have on a planetary mission than a lighter Kendall mass spectrometer. The ordinary

mass spectrometer can not only measure molecular weights of the major components and their relative abundance, but can quantitatively show trace constituents and, by having its beam energy varied, can distinguish between components of the same molecular weight. However, if the mission does not require accurate resolution of atmosphere components, and if instrument weight becomes an important factor, then the lightweight Kendall mass spectrometer may be of some value.

Operation of the ionless mass spectrometer on a Mars Soft Lander probe, where the chamber inlet pressure is the constant planet surface pressure, has already been discussed in Kendall's paper. What has not been considered in his paper, but will be examined in the following section, is operation feasibility of Kendall's mass spectrometer on a Mars probe (either Hard or Soft Lander) during its atmospheric entry phase.

Kendall Mass Spectrometer Operation During Entry

An independent measurement of mean molecular weight during the final low-altitude entry phase (after high vehicle deceleration has terminated), coupled with simultaneous pressure measurements, would yield local atmospheric density. Then, local temperature could be derived once pressure, density, and mean molecular weight were known. This would serve as a check on existing techniques where total temperature and total and static pressure are measured, and are then used to determine mean molecular weight.

The modified Kendall mass spectrometer operation would be as follows. Inlet pressure (P_1 in Kendall's terminology) would be the entry vehicle stagnation pressure. Assuming a single hollow chamber which is initially evacuated, it can be shown that the chamber pressure (P_2 in Kendall's terminology) is given by the following expression:

$$P_2(t) = \int_o^t P_1(t-t') \; e^{-\frac{t'}{VKM^{1/2}}} \; \frac{dt'}{VKM^{1/2}}$$

or, solving for M:

$$M = \left[\frac{P_1(t)-P_2(t)}{VK \frac{dP_2}{dt}} \right]^2$$

with an accompanying uncertainty of:

$$\frac{dM}{M} = 2 \left[\frac{d(P_1-P_2)}{P_1-P_2} + \frac{d\left(\frac{dP_2}{dt}\right)}{\frac{dP_2}{dt}} \right]$$

In the above expressions, VK is a function of the chamber and orifice geometry and, as Figure 2 shows, t' is a variable ranging from o to t. Thus, in-flight measurements of $P_1(t)$ and $P_2(t)$ at one time point are sufficient to yield M. Of course, measurements would be taken at many time points to reduce the error in determining M, the mixture mean molecular weight.

In summary, it can be stated that the Kendall mass spectrometer appears to be a useful device for measuring effective molecular weight of a gas mixture, and might be a worthwhile instrument to consider for use on a Mars probe during its atmospheric entry phase.

R. N. Kostoff

1014-RNK-jan

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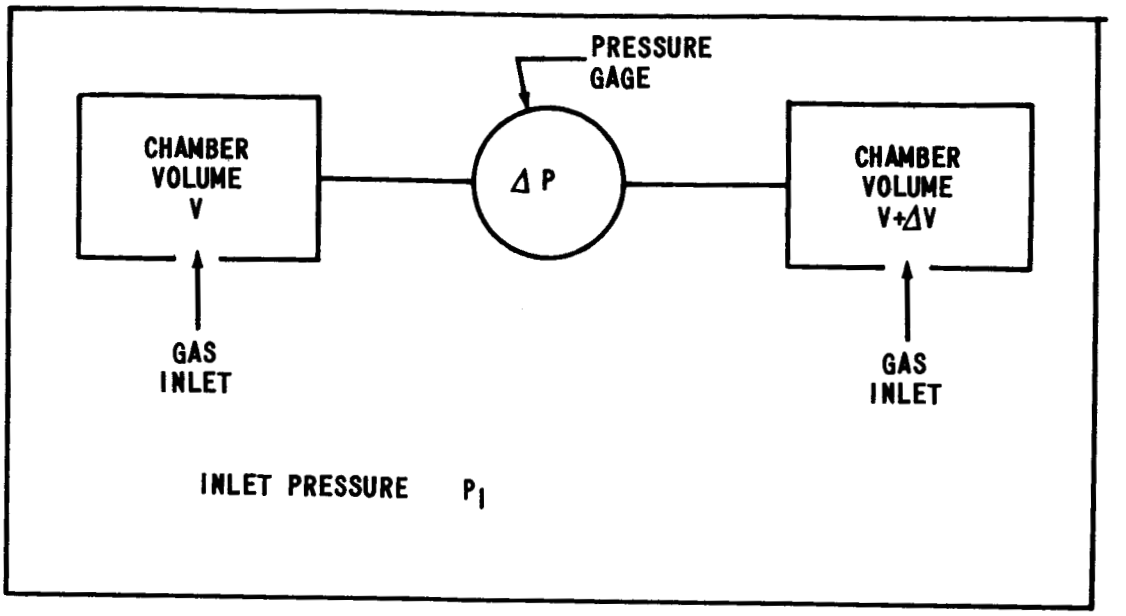
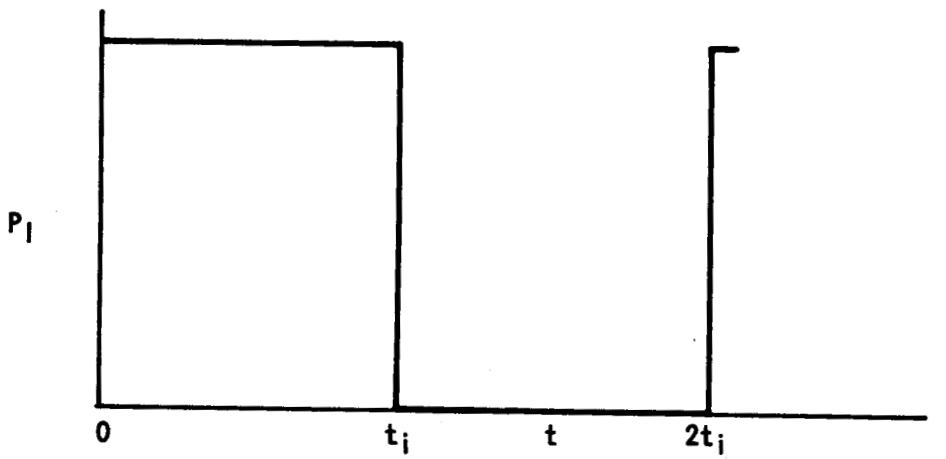
Attachment
Figures 1 and 2

REFERENCES

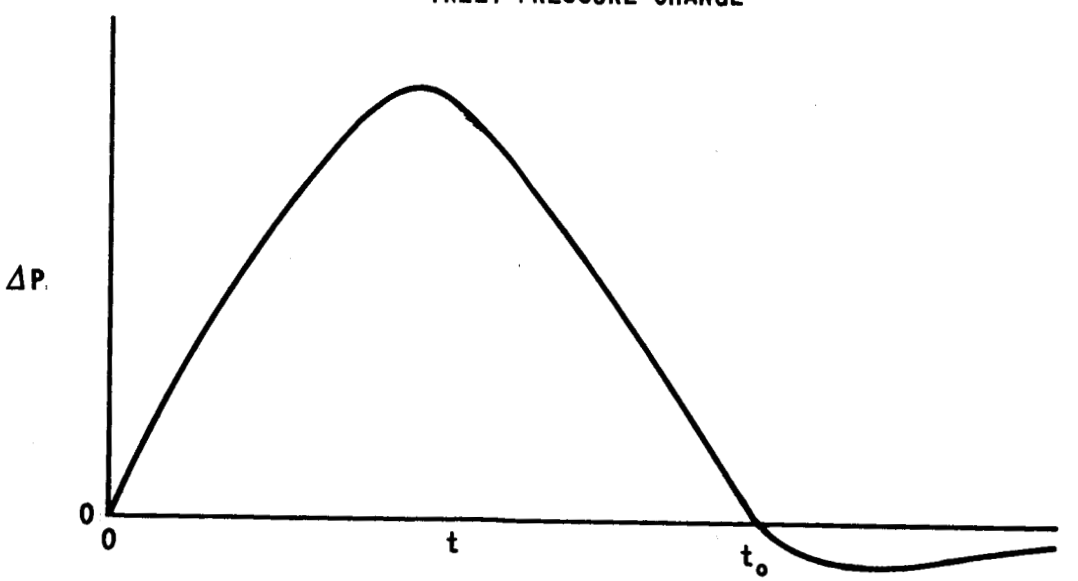
1. Kendall, B. R. F., and Pulfrey, R. E., "Gas Analysis with Pulsed Vacuum Networks," 4th International Vacuum Congress, Manchester, England, 1968.



EXPERIMENT SCHEMATIC



INLET PRESSURE CHANGE



CHAMBER PRESSURE RESPONSE

FIGURE 1 - LABORATORY EXPERIMENTAL SYSTEM

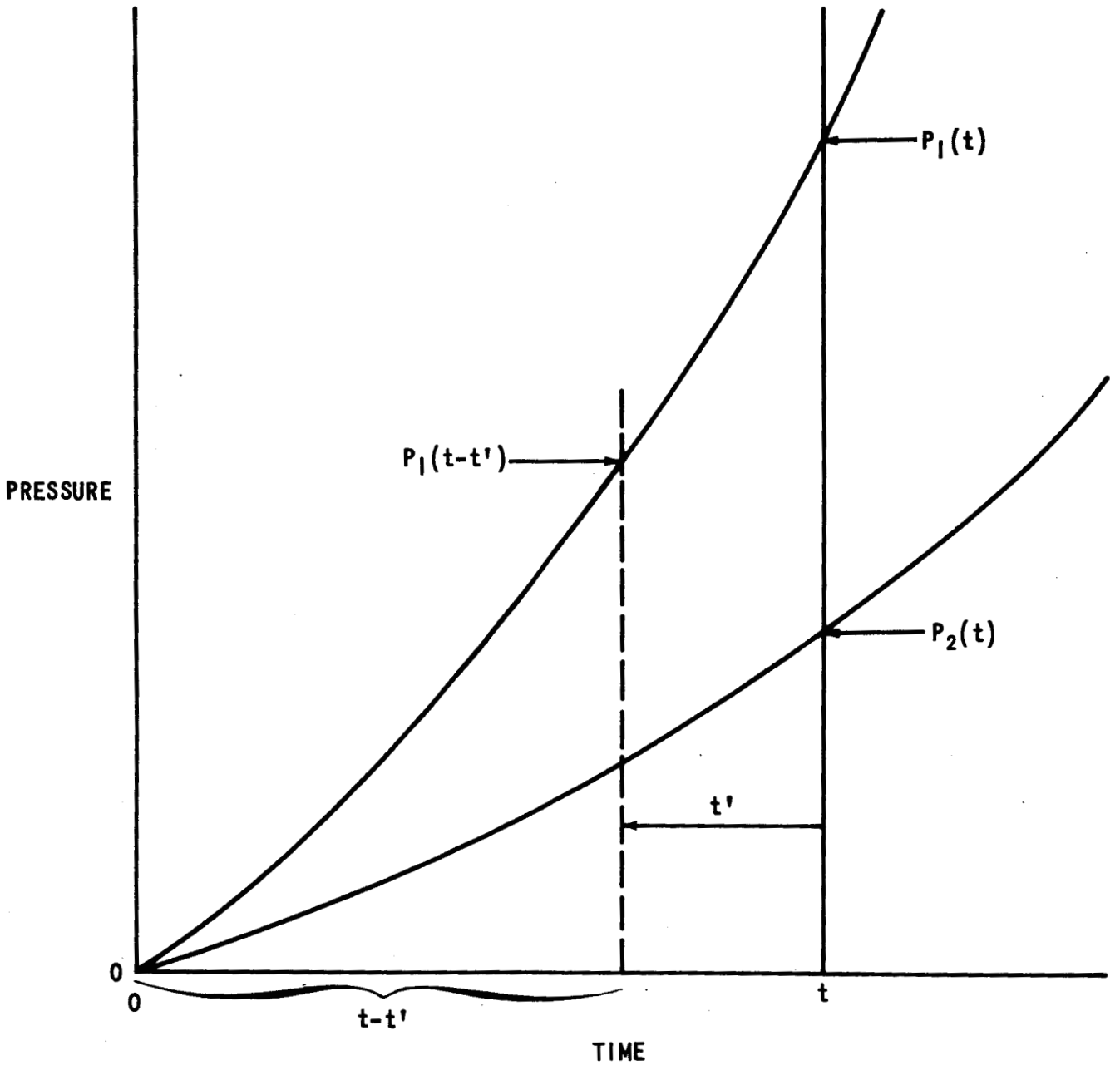


FIGURE 2 - SYSTEM PRESSURE RESPONSE ON ENTRY PROBE

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